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The Elimination of erosion phenomena in the main cooling water pumps in thermo power plant (TPP) "Kosova B" : [presentation given October 7, 2009]

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Master of Science in Professional Studies

Capstone Project

The Elimination of the Erosion Phenomena in the Main Cooling Water Pumps in Thermal Power Plant "Kosova B"

Presented by

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- **Introduction**
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Introduction

This Capstone Project will address the erosion phenomena on the impeller blades of the main cooling water pumps in Thermal Power Plant (TPP) “Kosova B”. The focus is on pumps suction line or the line between the cooling tower basin and the pumps intake

TPP “Kosova B”

TPP “Kosova B” has two units

- B1 -- 339 [MW]
- B2 -- 339 [MW]

The cooling system is one of the largest and most complex systems in TPP “Kosova B”

The cooling system includes

- Cooling water
- A cooling tower
- Four cooling water pumps (or two per unit)
- Pipes and fitting

Cooling Water

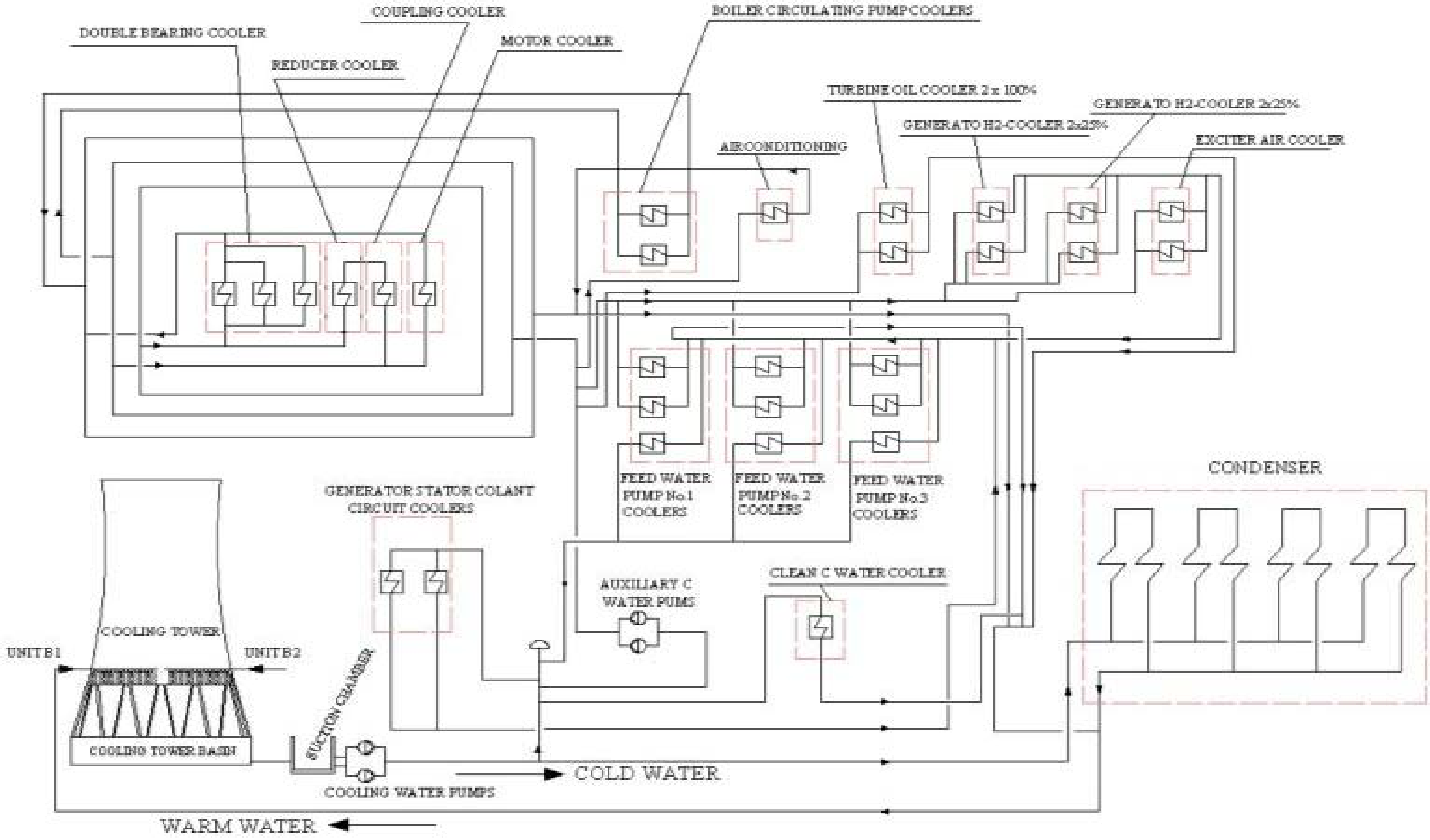
….. water used for cooling is taken from Decarbonized Water Treatment Plant

- Inhibitors against scaling or deposit formation (3DT 149)
- Inhibitors against corrosion (N-73190)
- Biological inhibitors (a mixture of N-3434 and NaOCL)

Cooling water is used for:

- Condenser
- Turbine oil coolers
- Generator hydrogen coolers
- Exciter air coolers
- Feed water pumps oil coolers and
- Coal mills oil coolers

Cooling Water Scheme

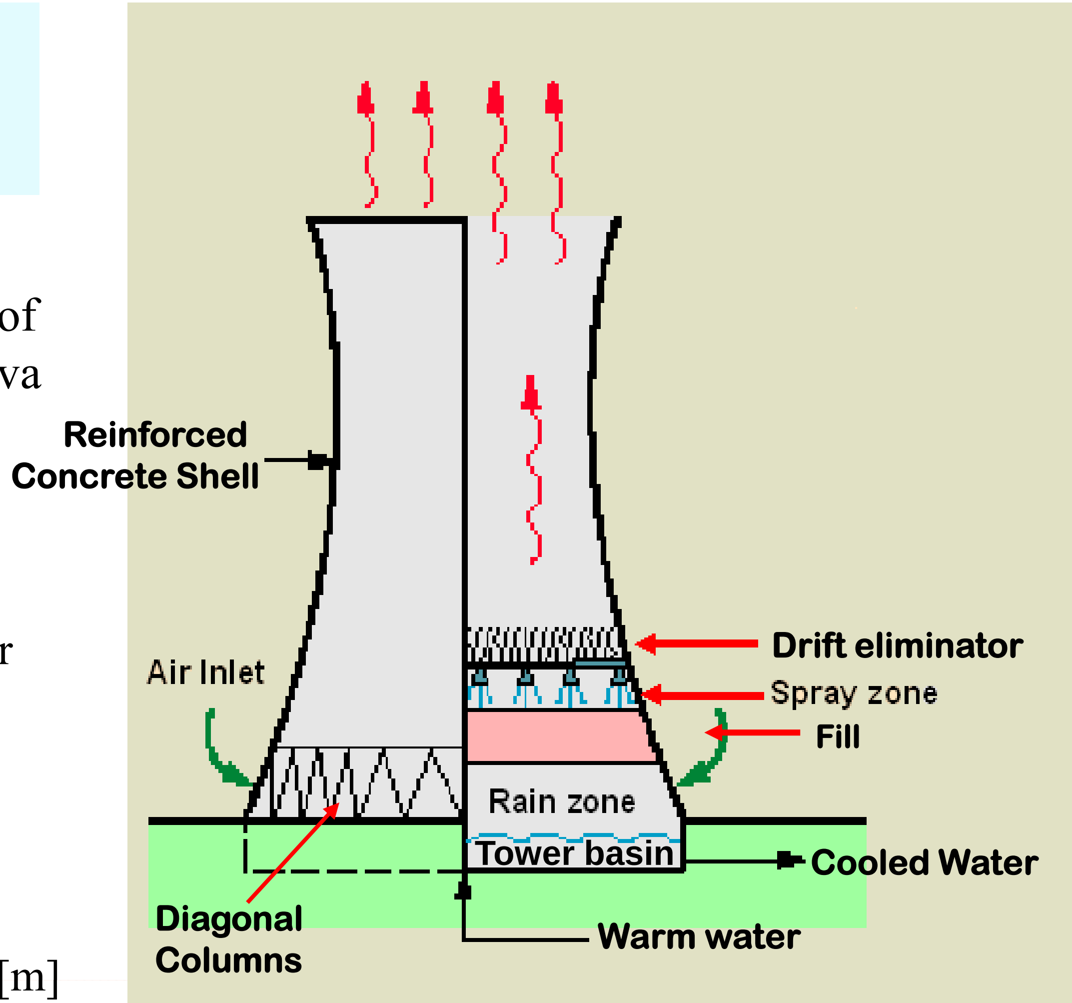


Cooling Tower

The primary task of the cooling tower to reject heat into the atmosphere

The technical data and features of the cooling tower at TPP "Kosova B"

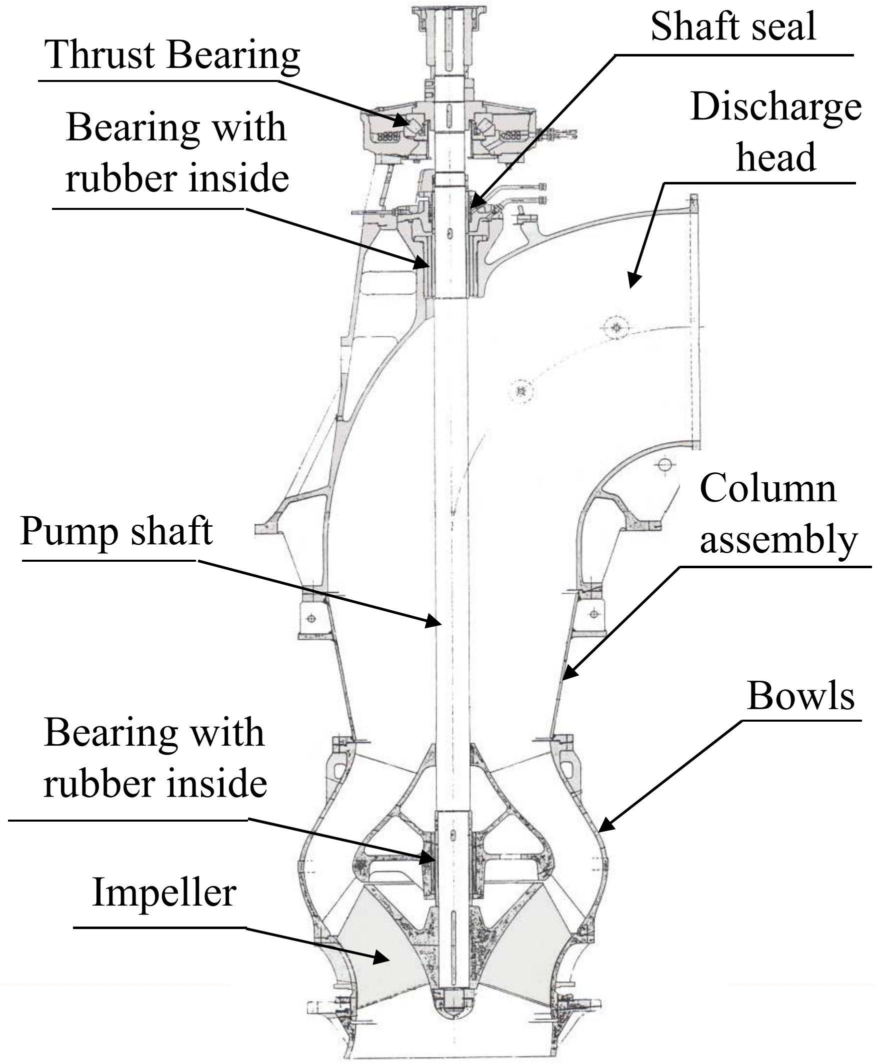
- The type of the cooling tower: "Natural draught cooling tower"
- The height of the cooling tower basin: 132 [m]
- The diameter of the cooling tower basin is 103 [m]
- The total depth of the cooling tower basin is 1.8 [m], where 1.6 [m]



Main Cooling Water Pump

The technical data and features of the main cooling water pumps at TPP "Kosova B"

- Pumps manufacturer CCM SULZER
- The pump water capacity is 4.84 [m3/s]
- The power of the driver motor is 1.3 [MW]
- The supply voltage of driven motor is 6.3 [KV]
- The current through phases is 148 [A]
- The number of rotations is 495 [rpm].
- Single stage mixed pumps.
- Bronze intermediate bearings with rubber inside.
- Bronze impeller.
- Shaft sealing by means of soft packing.



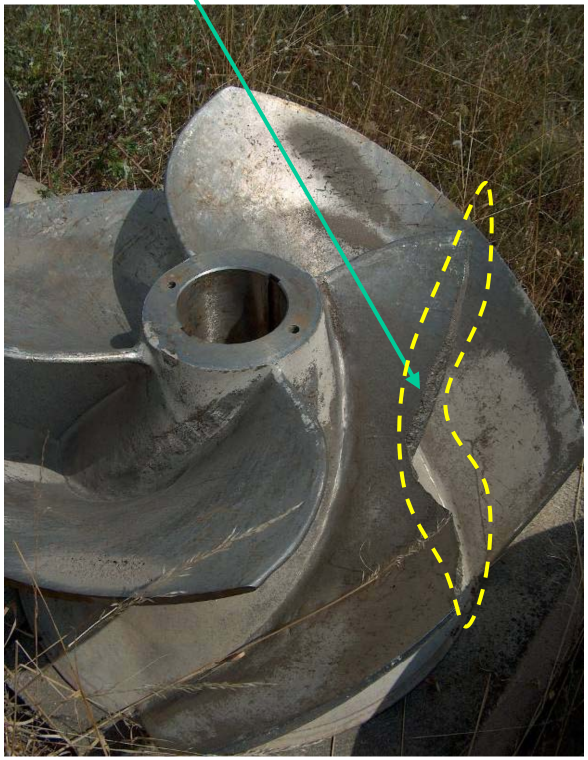
Problem Background

The erosion phenomenon has existed since the very beginning of the TPP "Kosova B" operation (since 1986), but has never been analyzed before

The surfaces of the impeller blades affected from the erosion phenomena

The broken blade due to the slimming of the blade thickness in the affected place from the erosion

Cavitation occurs when the pump cannot get enough liquid and the resulting reduction in pressure causes liquid to vaporize and form bubbles



Project Description - Resources

Necessary Resources for conducting the Capstone Project

- The archives in the library at TPP “Kosova B”
- The library in the Mechanical Faculty at the University of Prishtina
- The library in the Mechanical Faculty at the University of Tirana
- Documents related to this problem from the library of the CCM SULZER

Recourses form Master Program at AUK

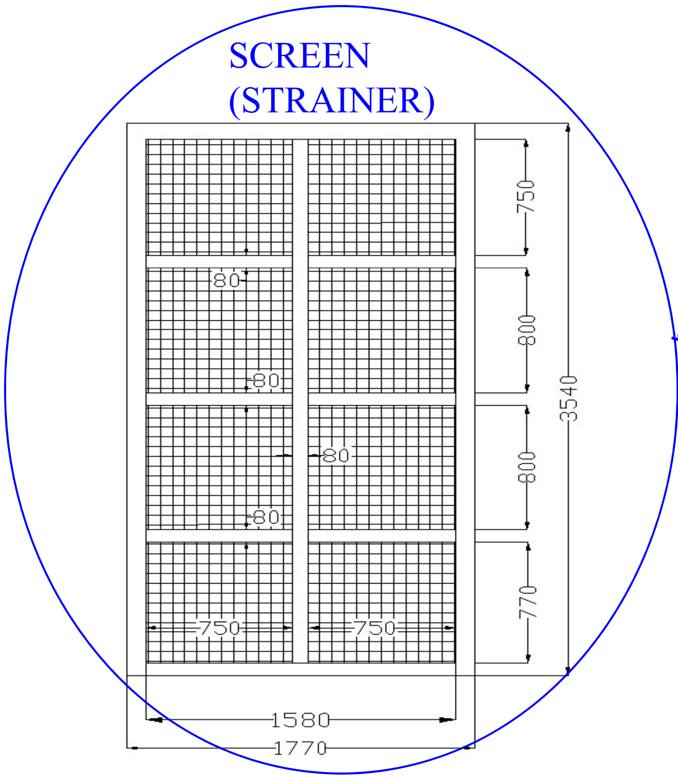
- Context an Trends
- Introduction to Project Management
- Asset Management
- Advanced Project Management

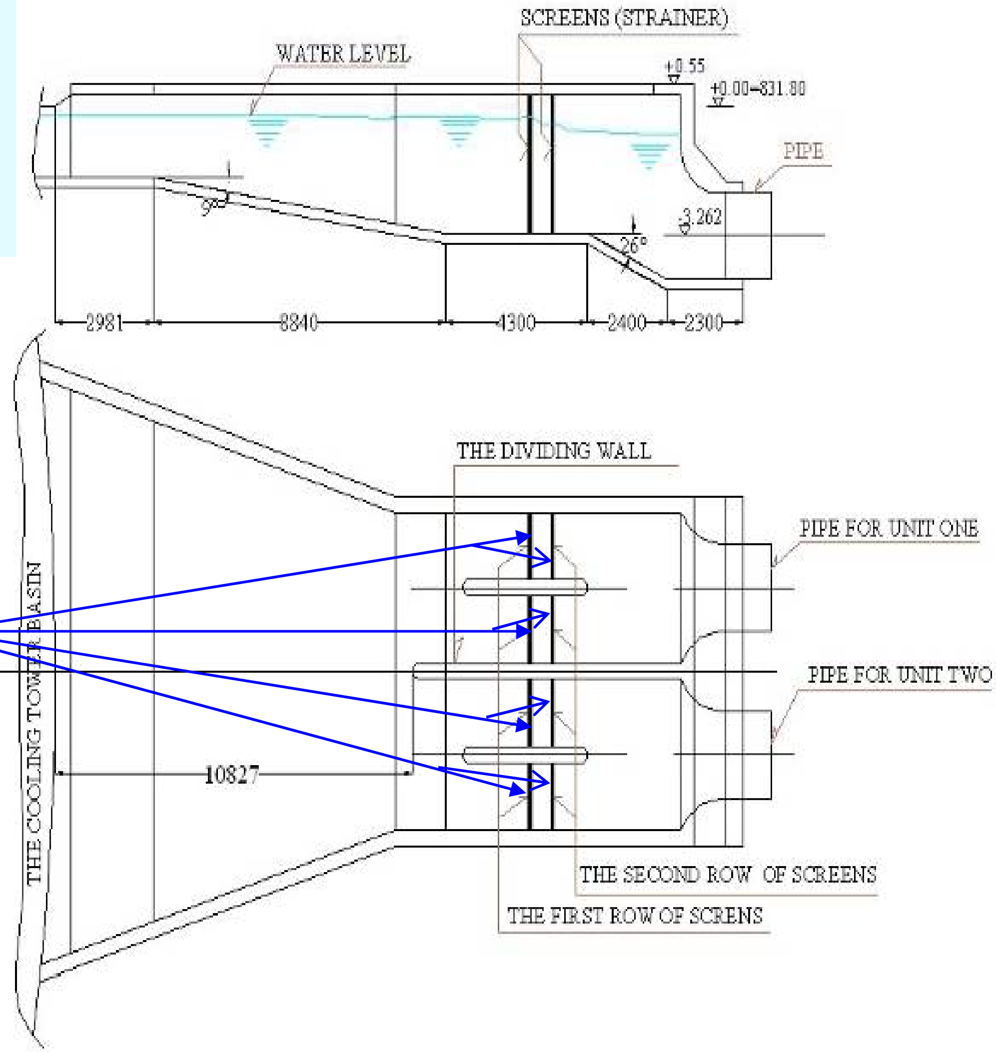
Project Description – Steps

- First step – Collection of information pertaining to the pumps suction line
- Second step -- Collection of reference books and web sites that have to do with Fluid Mechanics, Water Quality , Mixed Flow Pumps and Cooling Towers.
- Third step -- The measurement of the water velocity
- Fourth step -- Water flow definition and defining the friction factor
- Fifth step -- The analyze of the devices efficiency (pumps plus driver motors)
- Sixth step – Calculation of head losses through suction line, and
- Last step – Calculation of Net Positive Suction Head (NPSH)

Open Channel Description

The open channel, at a length of 10.827 meters, is a common channel for both units, B1 & B2, which is divided into two identical channels through a dividing concrete wall





Pipeline Description

The dimensions and features of the pipe line are as follows

L_1 = 42 [m] – is the length of the first part of the pipeline

L_2 = 42 [m] – is the length of the second part of the pipeline

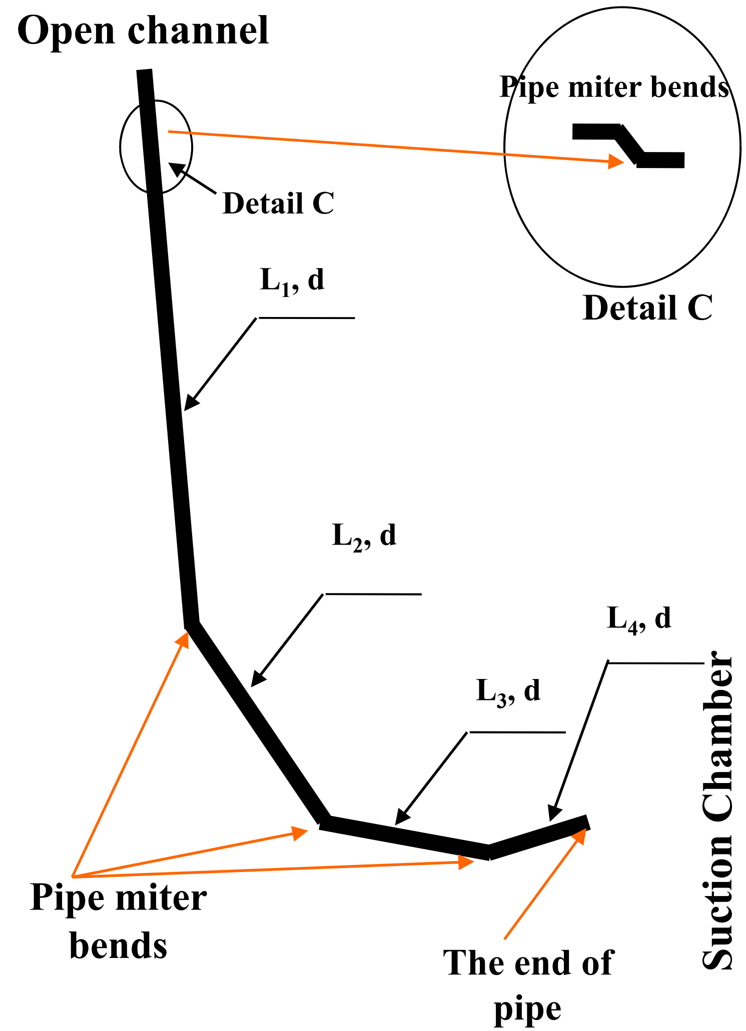
L_3 = 42 [m] - the length of the third part of the pipeline

L_4 = 42 [m] - the length of the fourth part of the pipeline

d = Ø 2176 [mm] = Ø 2.176 [m] – is the pipe inner diameter

δ = 22 [mm] – the wall thickness of the round pipe,

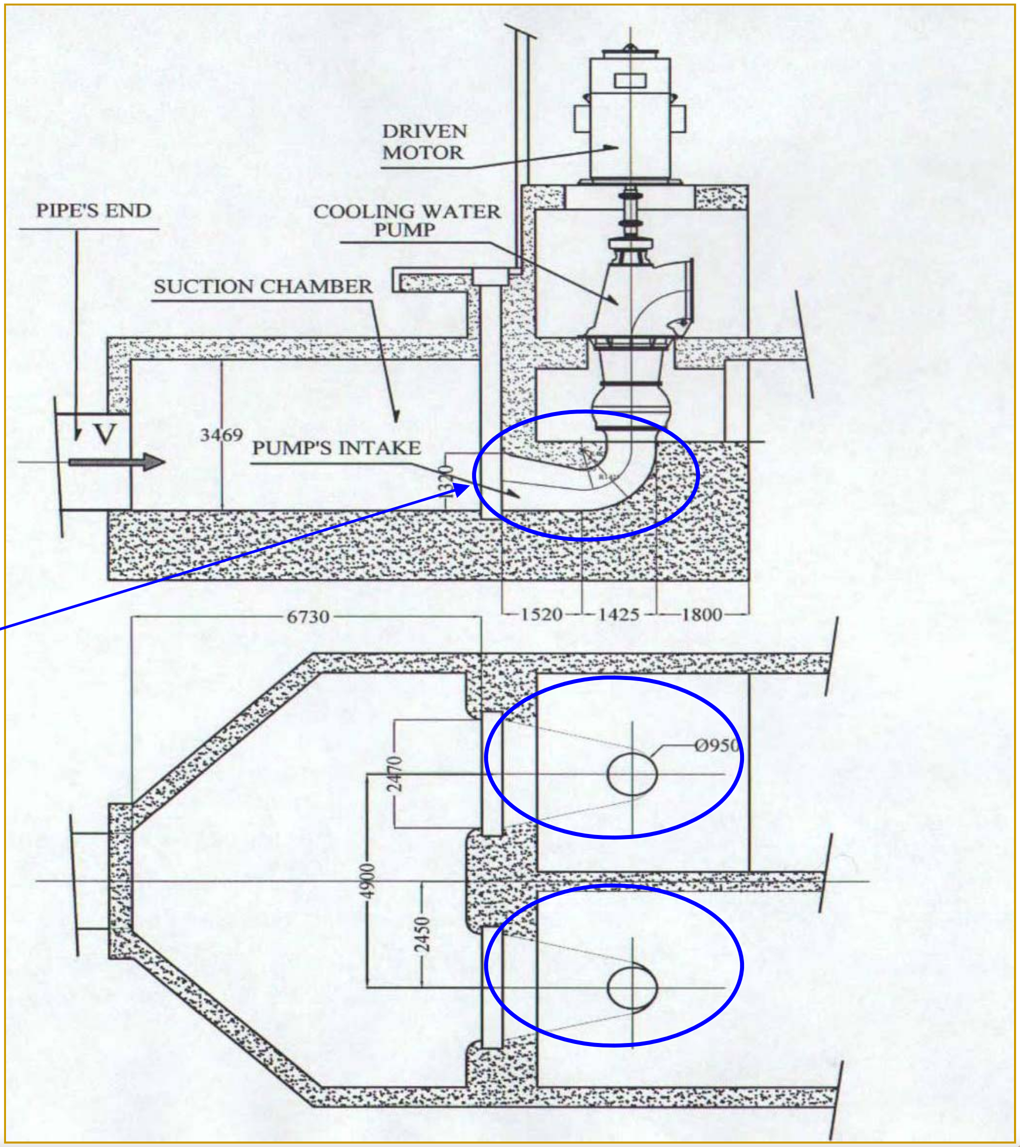
$A = \frac{3.14 \cdot d^2}{4} = 3.72 [m^2]$ -- Pipe cross section area



Suction Chamber Description

The suction chamber is common chamber for the two cooling water pumps that are placed in parallel

The shape of the pump's intake is a duct with the sudden contraction



Devices Efficiency

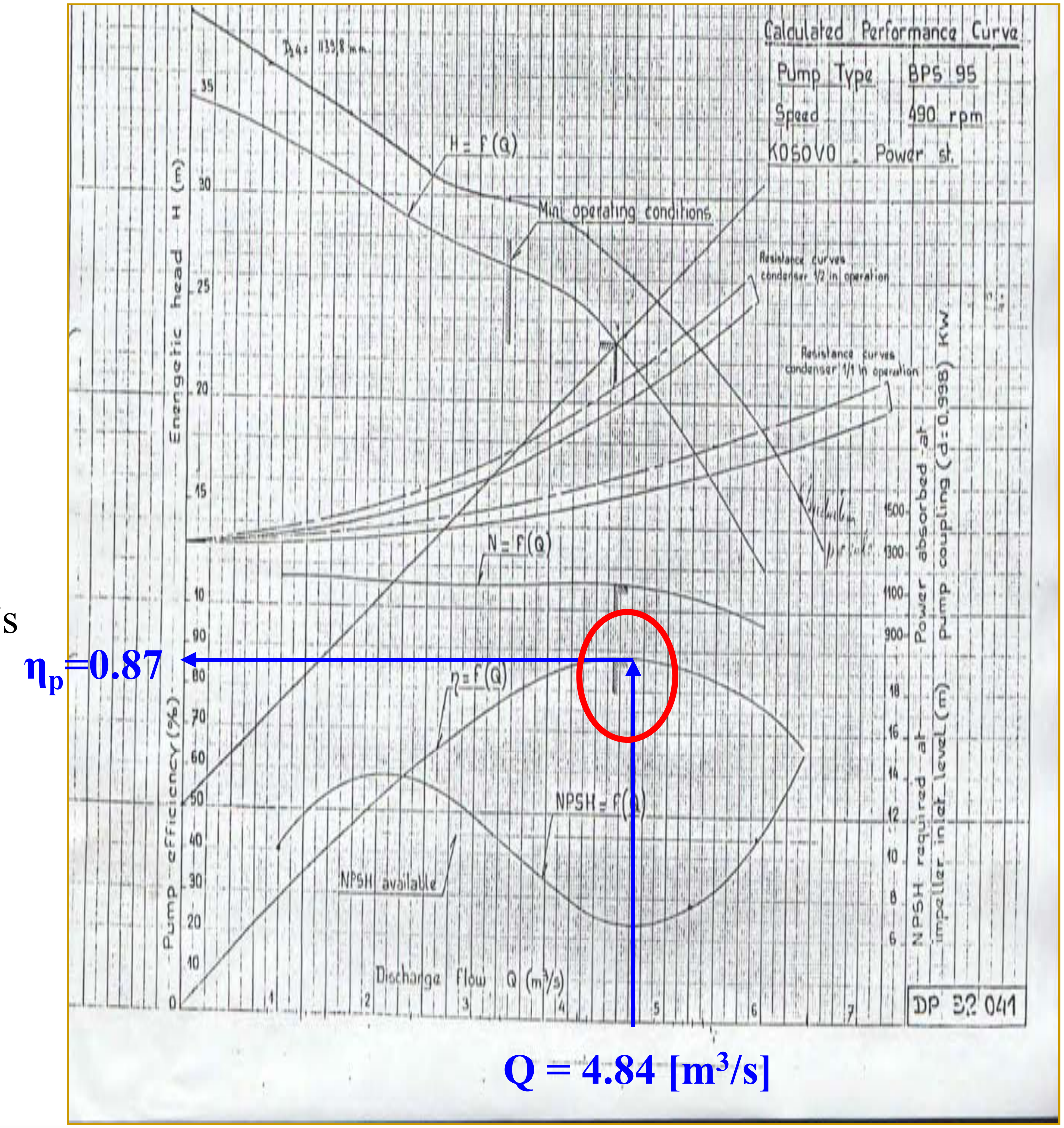
Real pump capacity

$Q_p = \eta_p$ x Q = 17427.84 [m/h] = 4.84 [m/s]

Where:

Q = 20032 [m3/h] -- is the ideal pump's capacity

η_p = 0.87 – is the pump efficiency



Devices Efficiency

$$\eta_{p1} = \eta_{p2}$$

$$\eta_{p1} = \eta_{p2} = \frac{P_{MECH}}{P_{EL}} = 0.82$$ -- The total efficiency of a device (pump & driver motor)

$$\eta_{tot} = \eta_{p1} \cdot \eta_{p2} = 0.82 \cdot 0.82 = 0.67$$ -- The total efficiency of devices (pumps & driver motors)

Where

$P_{MECH} = Q_p \text{ x } p_p$ = 1084160 [W] = 1084.16 [KW] – The mechanical power of pump

p_p=2.24 [bar] = 2.24 x 10^5 [N/m^2] – is the pump discharge pressure

P_{EL} = I x U x cosφ x 3^(0.5) = 1327.50 [KW] – the Electrical power of driver motor

I = 145 [A] -- current

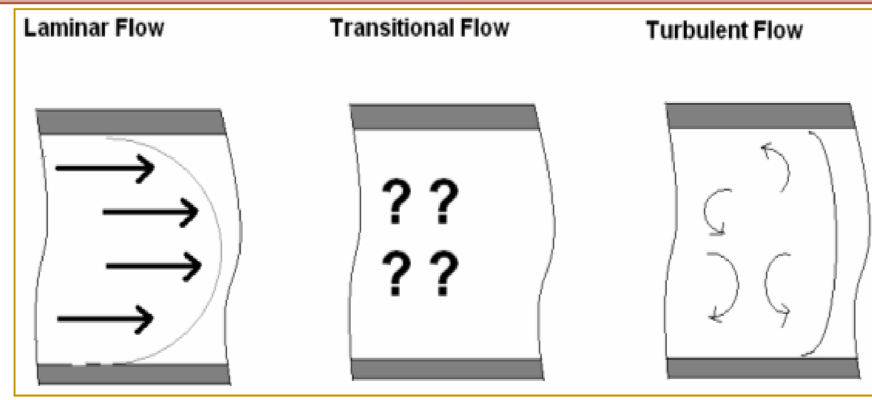
U = 6.3 [KV] – supply voltage

cosφ = 0.84 – the power factor

Water Flow Definition

The water flow may be:

- Laminar Re < 2000
- Transitional   2000 < Re > 4000
- Turbulent Re > 4000



The forms of water flows

$$Re = \frac{\rho \cdot d \cdot V}{\mu}$$ -- the Reynolds number for water flow through the pipeline

ρ = 994.08 [kg/m3] – is the water density for the cooled water temperature at 35 [°C]

d = Ø 2.176 [m] – is the pipe inner diameter,

μ = 0.00072 [kg/m s] – is the dynamic viscosity of water at 35 [°C]

- For only one pump in operation

$Re_{pipe(I)} = (\rho \text{ x } d \text{ x } V_{(I)} / \mu) = 3.905 \text{ x } 10^6 > 4000$

- For two pumps in parallel operation

$Re_{pipe(I)} = (\rho \text{ x } d \text{ x } V_{(II)} / \mu) = 3.905 \text{ x } 10^6 > 4000$

Water Flow Definition

- For only one pump in operation

$Re_{channel(I)} = Re_{pipe(I)} / 4 = 0.976 \times 10^6 > 4000$

- For two pumps in parallel operation

$Re_{channel(II)} = Re_{pipe(II)} / 4 = 1.32 \times 10^6 > 4000$

- Friction factor

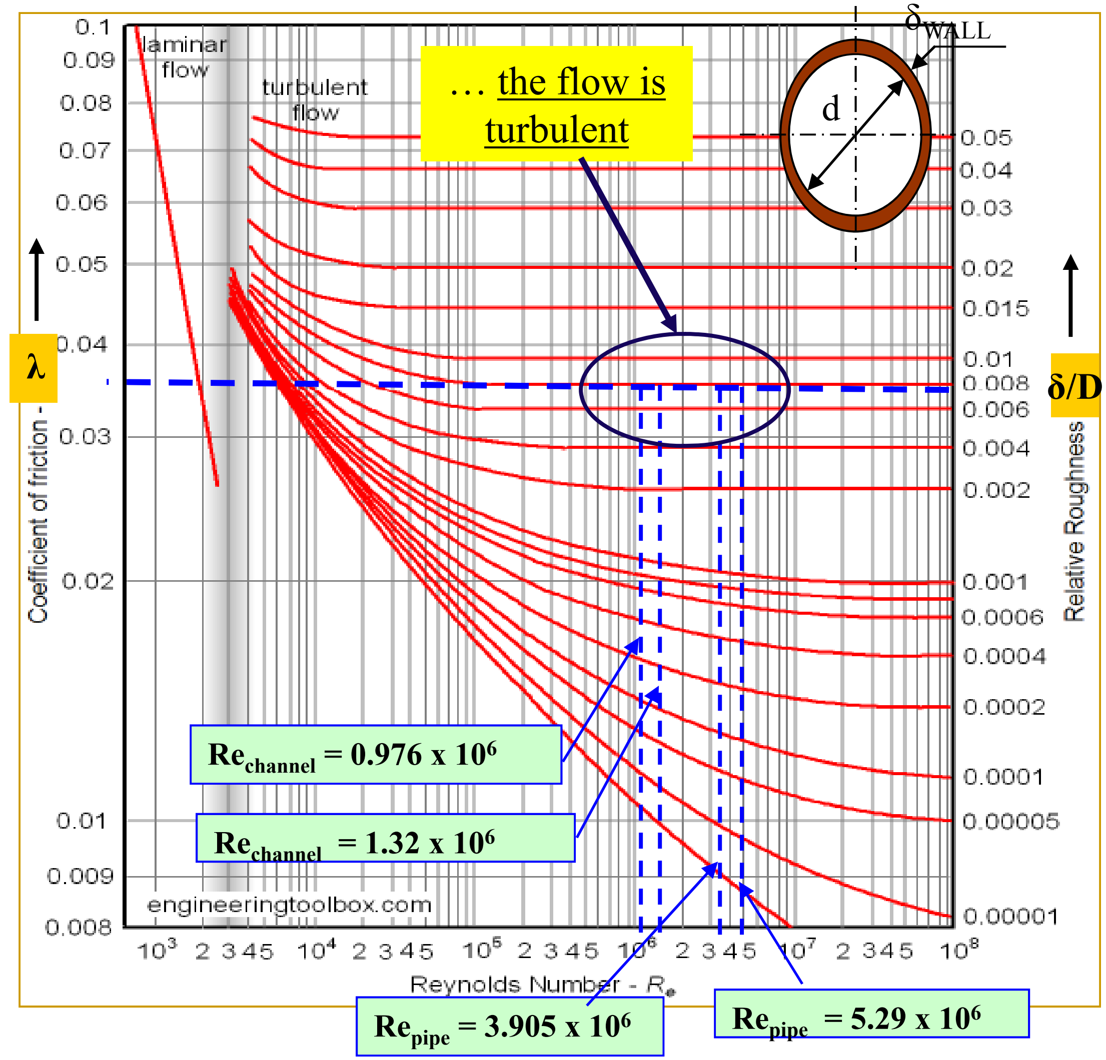
$\lambda = f(\delta_{WALL}/d; Re)$

where:

$\delta_{WALL} = 22$ [mm] – is the pipe wall thickness

$d = 2176$ [mm] –is the pipe inner diameter

$\delta_{WALL}/d = (0.022/2.176) = 0.01$



Water Velocity

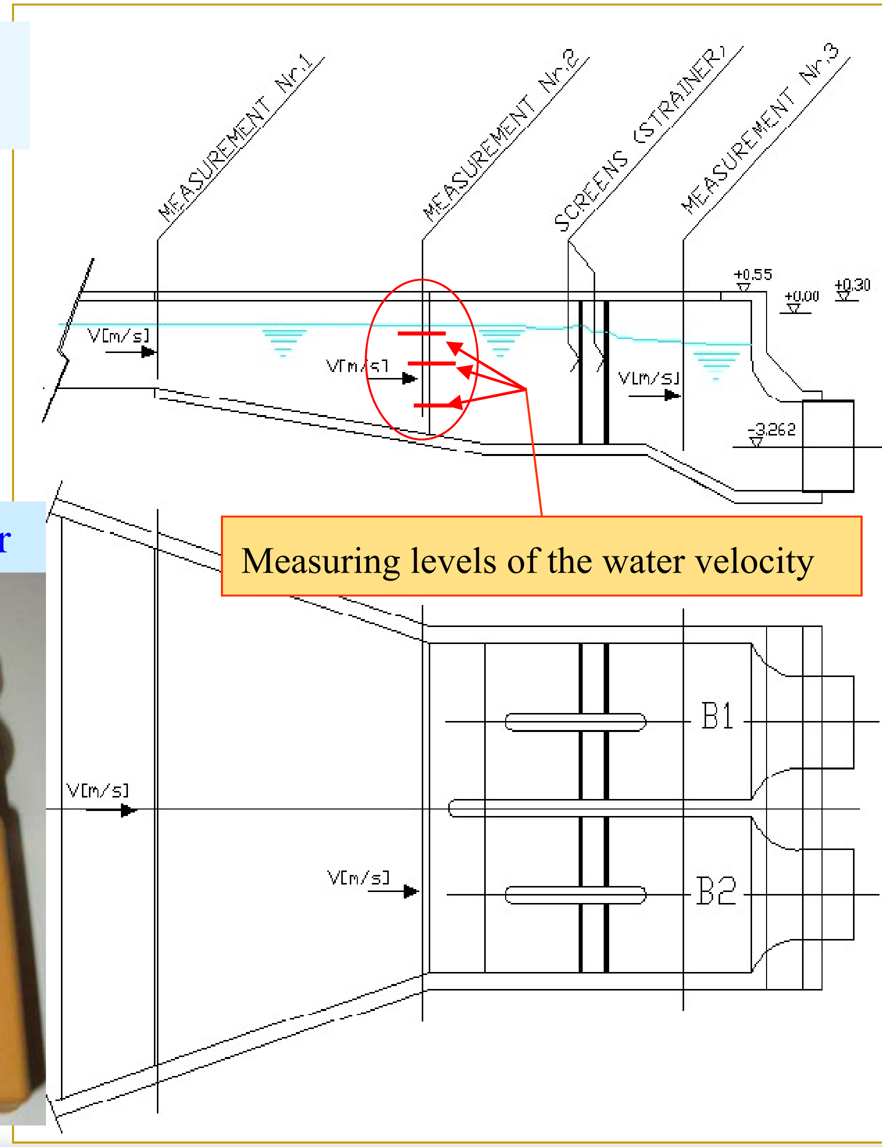
The measurement of the water velocity in the open channel is done by the INKOS Institute

Water Velocity V [m/s]		
Point 1	Point 2	Point 3
0.588	0.569	0.716
0.566	0.586	1.13
0.565	0.684	1.15

Noise [dB]
96
97
99

SEBA F2021

Sound Level Meter



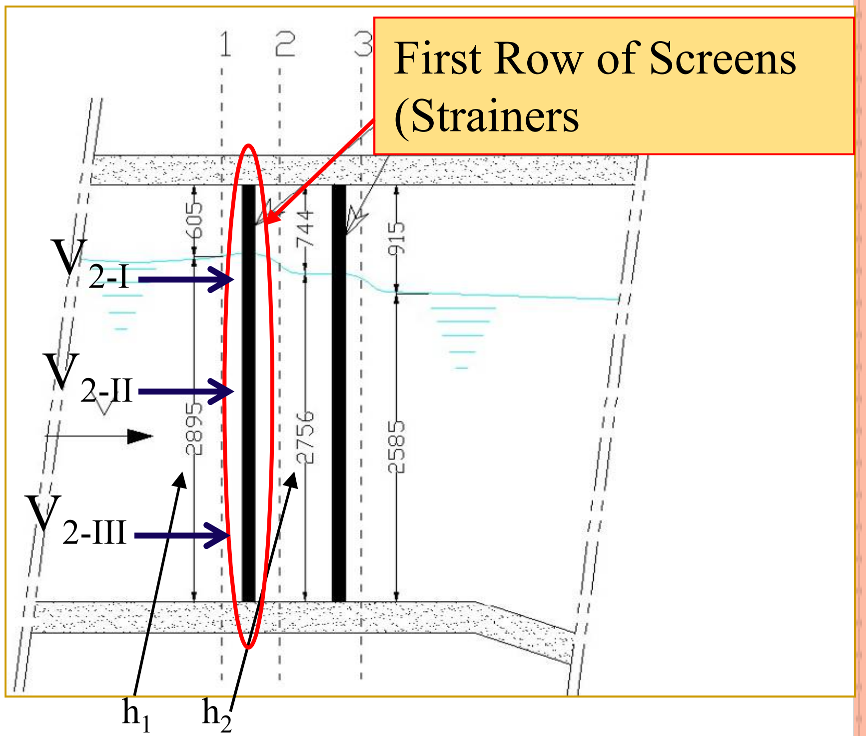
Losses Through First Row of Screens

- For only one pump in operation

$$H_{L-str1(I)} = h_1 + \frac{V_{(I)}^2}{2\cdot g} - h_2 - \left(\frac{Q_{(I)}}{A_{0-1}}\right)^2 \cdot \frac{1}{2\cdot g} = 0.127[m]$$

- For two pumps in parallel operation

$$H_{L-str1(II)} = h_1 + \frac{V_{(II)}^2}{2\cdot g} - h_2 - \left(\frac{Q_{(II)}}{A_{0-1}}\right)^2 \cdot \frac{1}{2\cdot g} = 0.109[m]$$



h_1 = 2.895 [m] – is the water depth before entering to first row of screens or strainers

h_2 = 2.745 [m] – is the water depth after first row of screens or strainers

$$V_{(I)} = V_{(II)} \cdot \frac{Q_{(I)}}{Q_{(II)}} = 0.46\left[\frac{m}{s}\right]$$ -- The water velocity before first row of screens

$$V_{(II)} = \frac{V_{2-I} + V_{2-II} + V_{2-III}}{3} = 0.613\left[\frac{m}{s}\right]$$ -- The water velocity before first row of screens for two pumps in parallel operation

Losses Through First Row of Screens

$$A_{0-1} = A_1 - \left(A_{w(H+V)} + A_{plate}\right) = 5.957[m^2]$$ -- The clear surface of screens or strainers

Where

$$A_1 = 2 \cdot W \cdot D = 9.01[m^2]$$ -- The total surface of submerged screens in water

Where

W = 1.58 [m] -- the width of useful screens or strainers

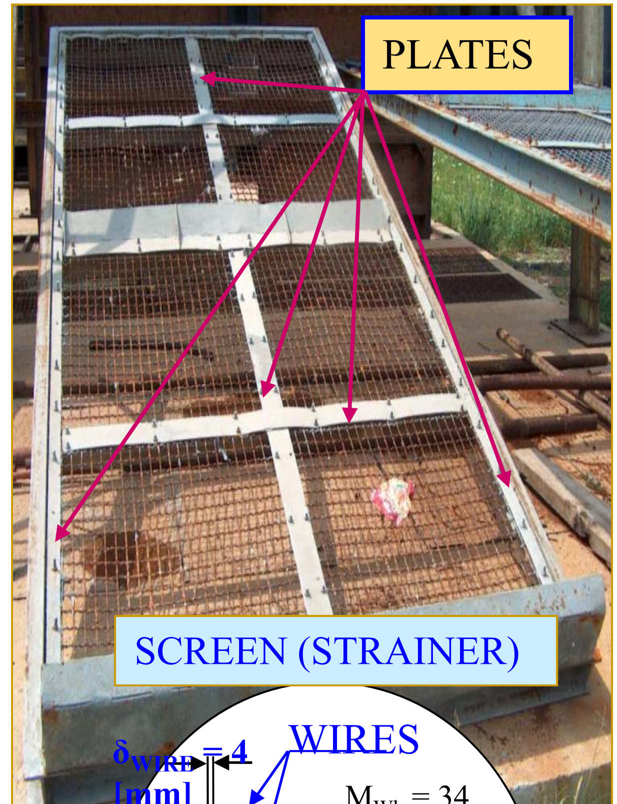
D = 2.85 [m] – the height of useful screens or strainers.

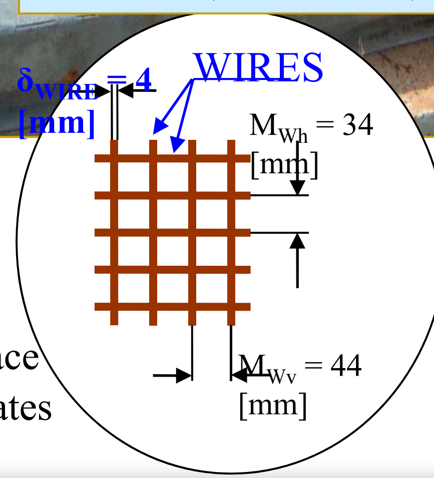
$$A_{w(H+V)} = 2 \cdot (A_{wh} + A_{wv}) = 1.877[m^2]$$ -- is the total occupied surface from the horizontal and vertical wires

$$A_{wh} = \delta_W \cdot L_h \cdot N_{wh} = 0.5297\ [m^2]$$ -- is the occupied surface from the horizontal wires

$$A_{wv} = \delta_W \cdot L_v \cdot N_{wv} = 0.409\,[m^2]$$ -- the occupied surface from the vertical wires

$$A_{plate} = 2 \cdot (2.85 \cdot 0.08 + 6 \cdot 0.75 \cdot 0.08) = 1.176[m^2]$$ -- The occupied surface of screens from the plates





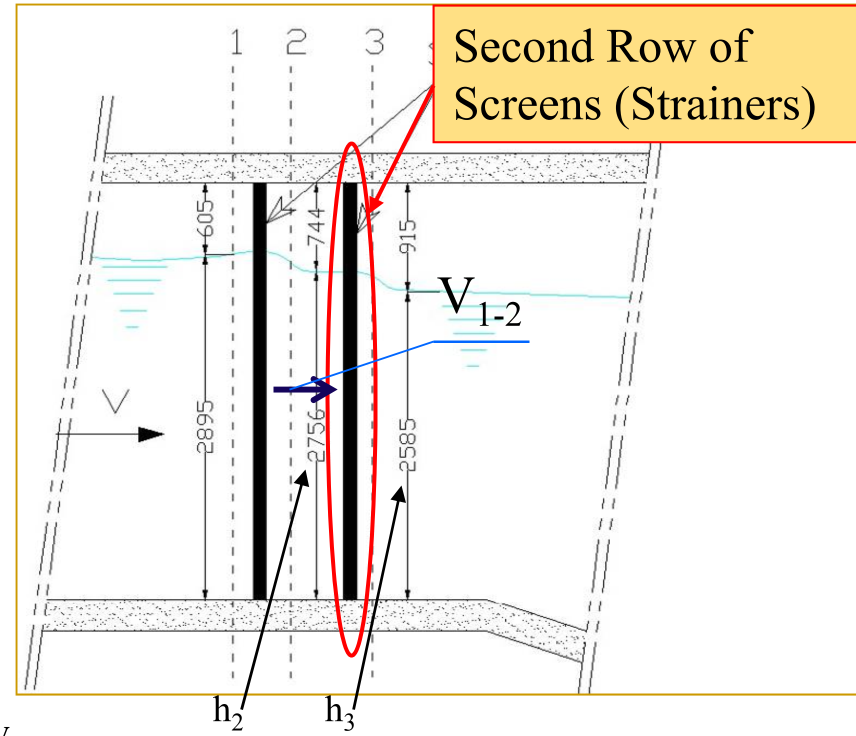
Losses Through Second Row of Screens

- For only one pump in operation

$$H_{L-str2(I)} = h_2 + \frac{V_{1-2(I)}^2}{2 \cdot g} - h_3 - \left(\frac{Q_{(I)}}{A_{0-2}}\right)^2 \cdot \frac{1}{2 \cdot g} = 0.129[m]$$

- For two pumps in parallel operation

$$H_{L-str2(II)} = h_2 + \frac{V_{1-2(II)}^2}{2 \cdot g} - h_3 - \left(\frac{Q_{(II)}}{A_{0-2}}\right)^2 \cdot \frac{1}{2 \cdot g} = 0.107[m]$$



Where

h_2 = 2.745 [m] – is the water depth before entering to the second row of screens or the water depth before the first row of the screens or strainers

h_3 = 2.745 [m] – is the water depth after the second row of screens or strainers

$$V_{1-2(I)}^2 = \frac{A_{0-1}}{A_1} \cdot V_{(I)} = 0.304\left[\frac{m}{s}\right]$$

-- the water velocity between the first and second row of screens or strainers for only one pump in operation

$$V_{1-2(II)}^2 = \frac{A_{0-1}}{A_1} \cdot V_{(II)} = 0.41\left[\frac{m}{s}\right]$$

-- the water velocity between the first and second row of screens or strainers for two pumps in parallel operation

Losses Through Second Row of Screens

$A_{0-2} = A_2 - \left(A_{w(H+V)} + A_{plate}\right) = 6.05[m^2]$ -- The clear surface of the second row of screens or strainers

Where

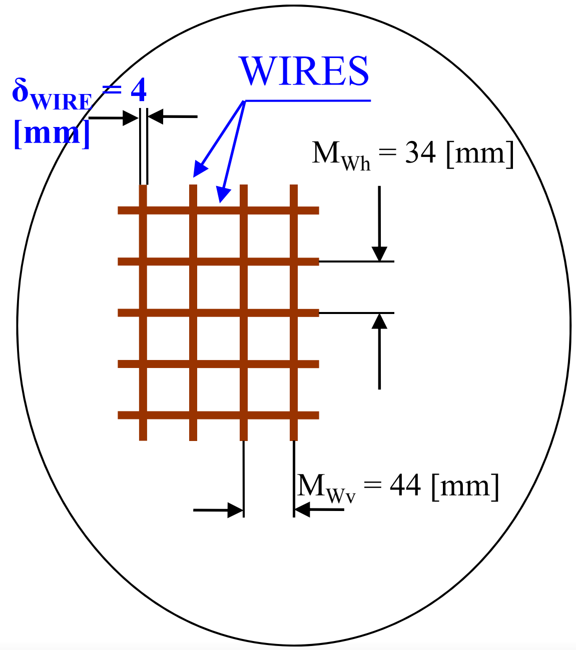
$A_2 = 2 \cdot W \cdot D = 8.564\ [m^2]$ -- The total surface of submerged screens in water

$A_{w(H+V)} = 2 \cdot (A_{wh} + A_{wv}) = 1.734[m^2]$ -- The total occupied surface from the horizontal and vertical wires

$A_{wh} = \delta_W \cdot L_h \cdot N_{wh} = 0.489[m^2]$ -- is the occupied surface from the horizontal wires

$A_{wv} = \delta_W \cdot L_v \cdot N_{wv} = 0.378[m^2]$ -- the occupied surface from the vertical wires

$A_{plate} = 2 \cdot (2.63 \cdot 0.08 + 6 \cdot 0.75 \cdot 0.08) = 1.14[m^2]$ -- The occupied surface of screens from the plates



Open Channel Total Head Losses

…..the sum of head losses through the first and second row of screens (strainers)

$$H_{L\text{-CHANNEL}} = H_{L\text{-str1}} + H_{L\text{-str2}}$$

- For only one pump in operation

$$H_{L-CHANNEL(I)} = H_{L-str1(I)} + H_{L-str2(I)} = 0.256[m]$$

- For two pumps in parallel operation

$$H_{L-CHANNEL(II)} = H_{L-str1(II)} + H_{L-str2(II)} = 0.216[m]$$

Pipeline Friction Head Losses

…. are caused due to friction between water and pipe wall

- For only one pump in operation

$$H_{LF(I)} = \lambda \cdot \frac{L}{d} \cdot \frac{V^2}{2 \cdot g} = \frac{Q_{p(I)}^2}{2 \cdot g \cdot A^2} \cdot \left(\lambda \cdot \frac{L}{d} \right) = 0.137[m]$$

- For two pumps in parallel operation

$$H_{LF(II)} = \lambda \cdot \frac{L}{d} \cdot \frac{V^2}{2 \cdot g} = \frac{Q_{p(II)}^2}{2 \cdot g \cdot A^2} \cdot \left(\lambda \cdot \frac{L}{d} \right) = 0.247[m]$$

Where

λ=0.0395 – friction factor (Moody chart)

L = L_1+ L_2+L_3+L_4=87.58 [m] – the total pipeline length

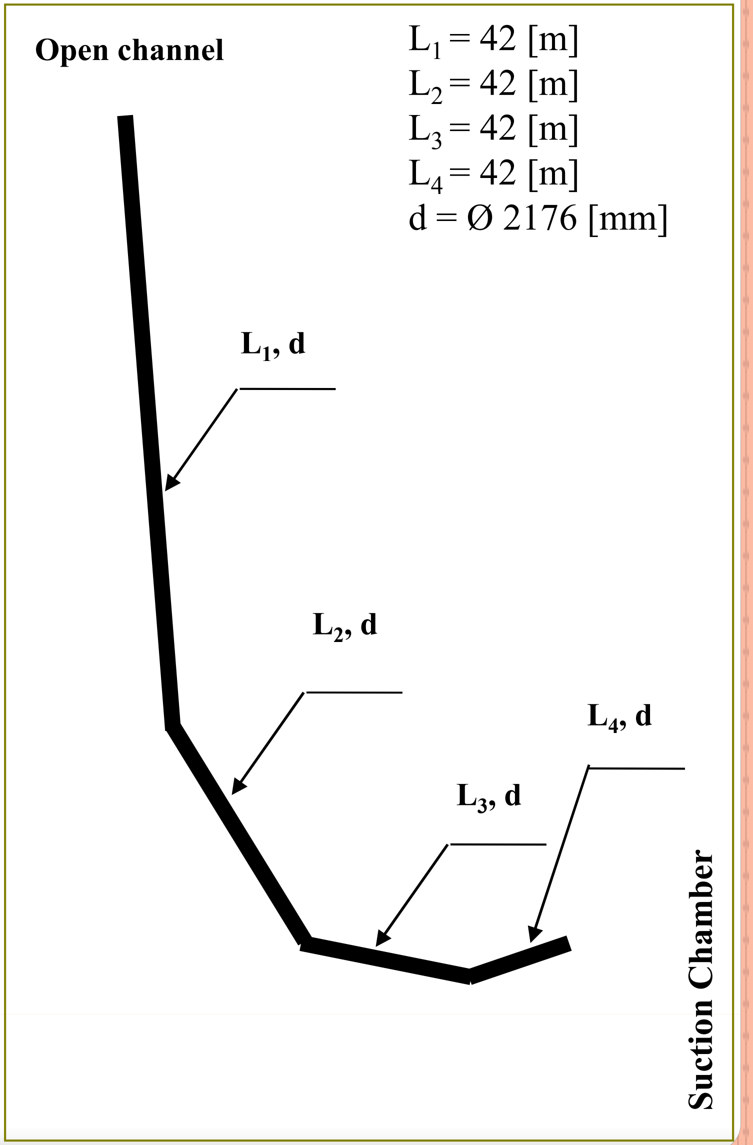
$Q_{(I)}$=Q_p=4.84 [m^3/s] – the capacity of only one pump

$Q_{(II)}$=(Q_{p1}+Q_{p2}) η_{tot} =(4.84+4.84) 0.67=6.486[m3/s] – the capacity of two pumps in parallel operation

A = 3.14 x d^2/4 [m^2] – The pipeline cross section area

d = Ø 2.176 [mm] – the pipe inner diameter

g = 9.81 [m/s^2] – acceleration due to gravity



Pipeline Minor Head Losses

….. are losses through the pipe miter bends are classified as “minor losses”. Minor losses include energy losses resulting from the rapid changes in the direction or the magnitude of the water velocity in the pipeline

- For only one pump in operation

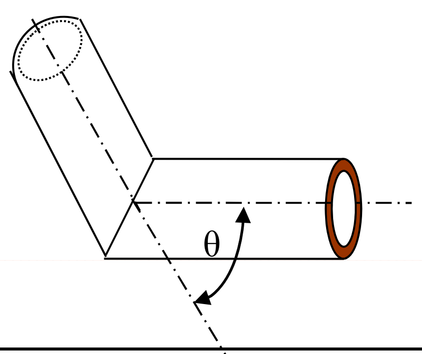
$$H_{LM\,(I)} = \frac{Q^2_{p(I)}}{2 \cdot A^2 \cdot g} \cdot \zeta = 0.248\ [m]$$

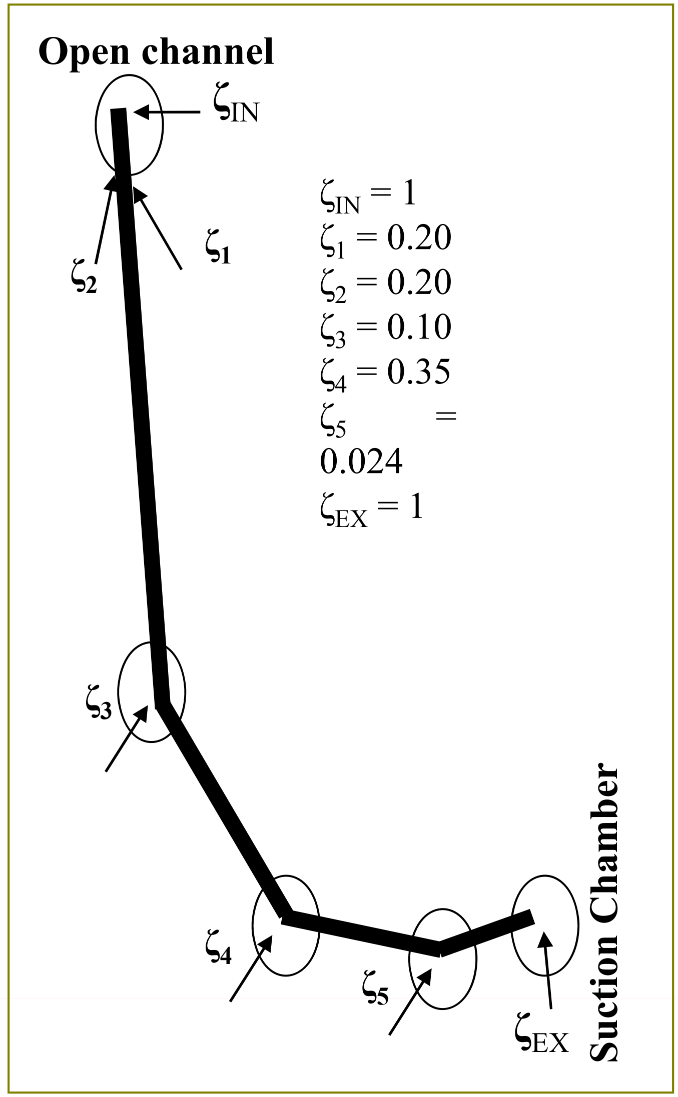
- For two pumps in parallel operation

$$H_{LM\,(II)} = \frac{Q^2_{p(II)}}{2 \cdot A^2 \cdot g} \cdot \zeta = 0.446\ [m]$$

Where

$\Sigma\zeta = (\zeta_{IN} + \zeta_1 + \zeta_2 + \zeta_3 + \zeta_4 + \zeta_{EX}) = 2.874$ -- the sum of coefficients due to pipe miter bends

Mitered Bend	Angle	ζ
	$\theta = 5^o$	0.016
	$\theta = 15^o$	0.05
	$\theta = 30^o$	0.10
	$\theta = 45^o$	0.20
	$\theta = 60^o$	0.35
	$\theta = 90^o$	0.80



Pipeline Total Head Losses

….. the sum of head losses due to friction and due to pipe miter bends

$$H_{L\text{-pipe(I)}} = H_{LF} + H_{LM}$$

Where

H_{LF} [m] -- are the head losses due to the friction in the pipeline

H_{LM} [m] -- are the head losses due to the minor losses (pipe miter bends) in the pipeline

- For only one pump in operation

$$H_{L\text{-pipe(I)}} = H_{LF(I)} + H_{LM(I)} = 0.137 + 0.248 = \underline{0.385}\ [m]$$

- For two pumps in parallel operation

$$H_{L\text{-pipe(II)}} = H_{LF(II)} + H_{LM(II)} = 0.247 + 0.446 = \underline{0.693}\ [m]$$

Pumps Intake Head Losses

…. are caused due to sudden contraction duct

- For only one pump in operation

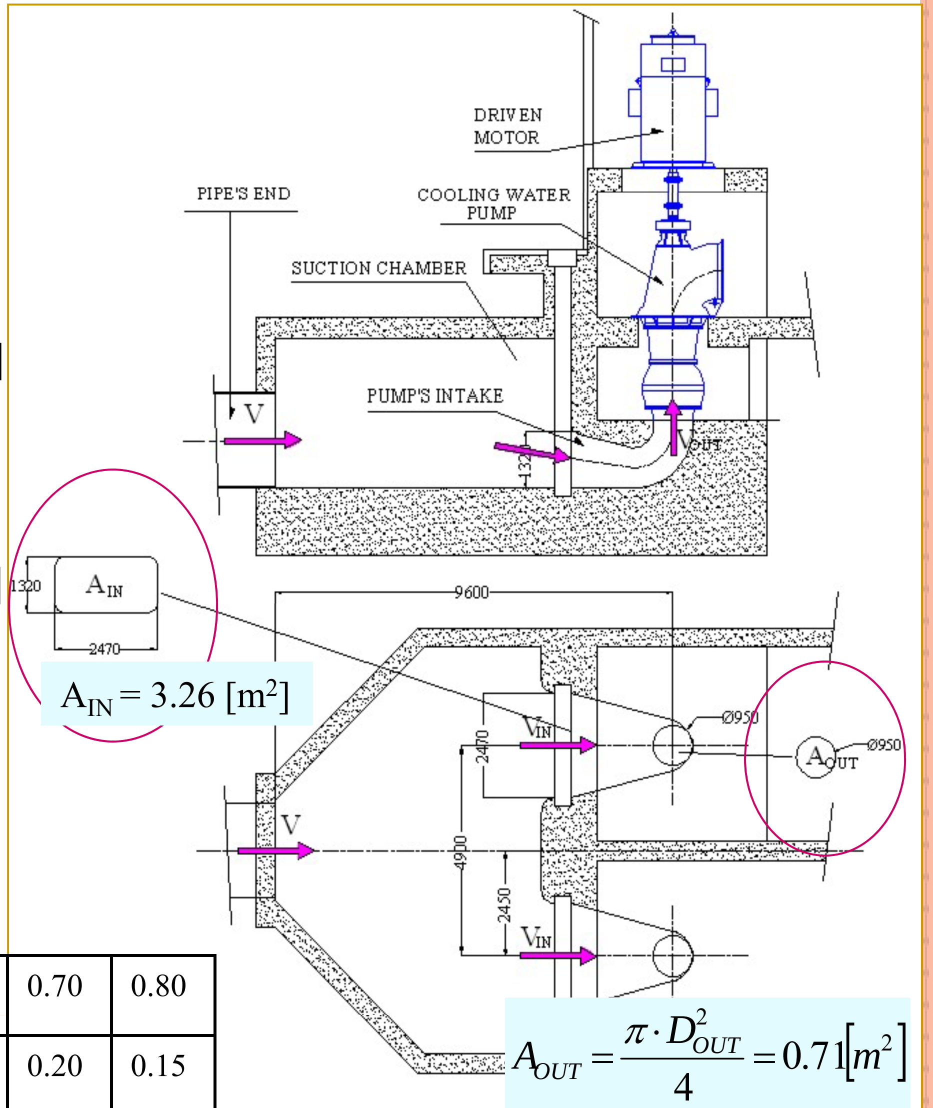
$$H_{L-CONTRACTION(I)} = \zeta_{CONTRACTION} \cdot \frac{V_{out(I)}^2}{2 \cdot g} = 0.18[m]$$

- For two pumps in parallel operation

$$H_{L-CONTRACTION(II)} = \zeta_{CONTRACTION} \cdot \frac{V_{out(II)}^2}{2 \cdot g} = 0.35[m]$$

Where

$$\zeta_{CONTRACTION} = 0.42 \quad \text{for} \quad \frac{A_{OUT}}{A_{IN}} = \frac{0.71}{3.26} = 0.22$$



$A_{IN} = 3.26\ [m^2]$

$$A_{OUT} = \frac{\pi \cdot D_{OUT}^2}{4} = 0.71[m^2]$$

A_{OUT}/A_{IN}	0.01	0.10	**0.20**	0.40	0.50	0.60	0.70	0.80
$\zeta_{CONTRACTION}$	0.05	0.49	**0.42**	0.33	0.30	0.25	0.20	0.15

Pumps Intake Head Losses

$V_{OUT(I)} = V_{IN(I)} \cdot \frac{A_{IN}}{A_{OUT}} = 2.93[\frac{m}{s}]$ -- The water velocity at the duct outlet for only one pump in operation

$V_{OUT(II)} = V_{IN(II)} \cdot \frac{A_{IN}}{A_{OUT}} = 4.07[\frac{m}{s}]$ -- The water velocity at the duct outlet for two pumps in parallel operation

$V_{IN(I)} = V_{Out-pipe(I)} \cdot (1 - \frac{L}{B}) = 0.64\left[\frac{m}{s}\right]$ -- The water velocity at the duct inlet only one pump in parallel

$V_{IN(II)} = V_{Out-pipe(II)} \cdot (1 - \frac{L}{B}) = 0.89\left[\frac{m}{s}\right]$ -- The water velocity at the duct inlet for two pumps in parallel operation

$V_{Out-pipe(I)} = 1.3\left[\frac{m}{s}\right]$ -- The water velocity at the outlet pipe or the water velocity at the suction chamber for only one pump in operation

$V_{Out-pipe(II)} = 1.7\left[\frac{m}{s}\right]$ -- The water velocity at the outlet pipe or the water velocity at the suction chamber for two pumps in parallel operation

L = 9600 [mm] = 9.6 [m] – is the distance from the pipe outlet to the centers of the

B = 4900 [mm] = 4.9 [m] – is the distance between the centers of the pumps

Suction Line Total Head Losses

…. are all losses caused due to screens or strainers that are placed in the open channel, friction between water and pipe wall, pipe miter bends and sudden contraction duct at pumps intake

$$H_L = H_{L\text{-CHANNEL}} + H_{L\text{-PIPE}} + H_{L\text{-INTAKE}}$$

Where

$H_{L\text{-CHANNEL}}$ [m] – Head losses through the open channel

$H_{L\text{-PIPE}}$ [m] – Head losses through the pipeline

$H_{L\text{-INTAKE}}$ [m] – Head losses through the pumps intake

- For only one pump in operation

$$H_{L(I)} = H_{L\text{-CHANNEL}(I)} + H_{L\text{-PIPE}(I)} + H_{L\text{-INTAKE}(I)} = 0.256 + 0.385 + 0.18 = \underline{0.821}\ [m]$$

- For two pumps in parallel operation

$$H_{L(II)} = H_{L\text{-CHANNEL}(II)} + H_{L\text{-PIPE}(II)} + H_{L\text{-INTAKE}(II)} = 0.216 + 0.693 + 0.35\underline{1.25}\ [m]$$

Net Positive Suction Head (NPSH)

…. is the head that is present at the suction side of the pump

$NPSH_A$ – should be calculated

$NPSH_R$ = 6.857 [m] -- from the pumps manufacturer

- For only one pump in operation

$$NPSH_{A(I)} = H_A + H_{ST} - H_{L(I)} - H_{VP} = 11.956[m]$$

- For two pumps in parallel operation

$$NPSH_{A(II)} = H_A + H_{ST} - H_{L(II)} - H_{VP} = 11.51[m]$$

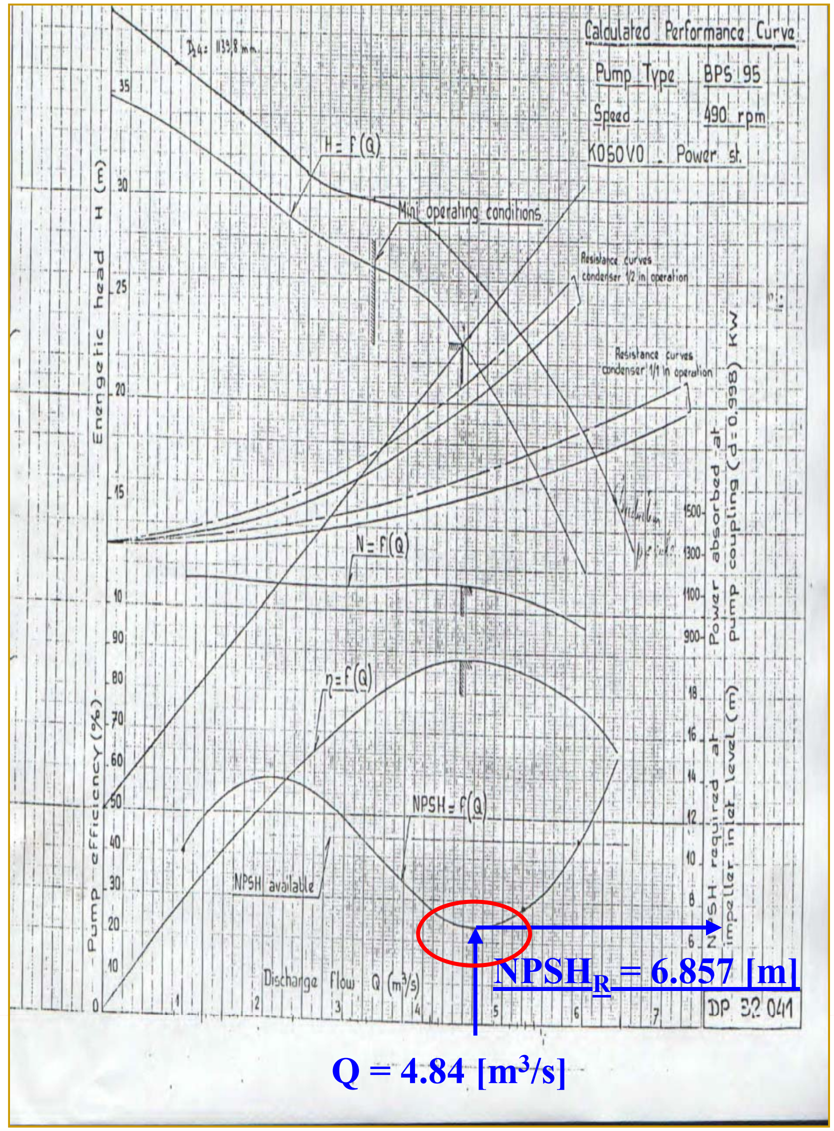
Where

$H_A = \dfrac{p_{atm}}{\rho \cdot g} = 9.75[m]$ -- the head due to the atmospheric pressure

$p_{atm} = 0.95[bar]$-- the atmospheric for the altitude of 531.80[m] above sea level

ρ = 994.08 [kg/m3] – the water density at 35 [^{0}C]

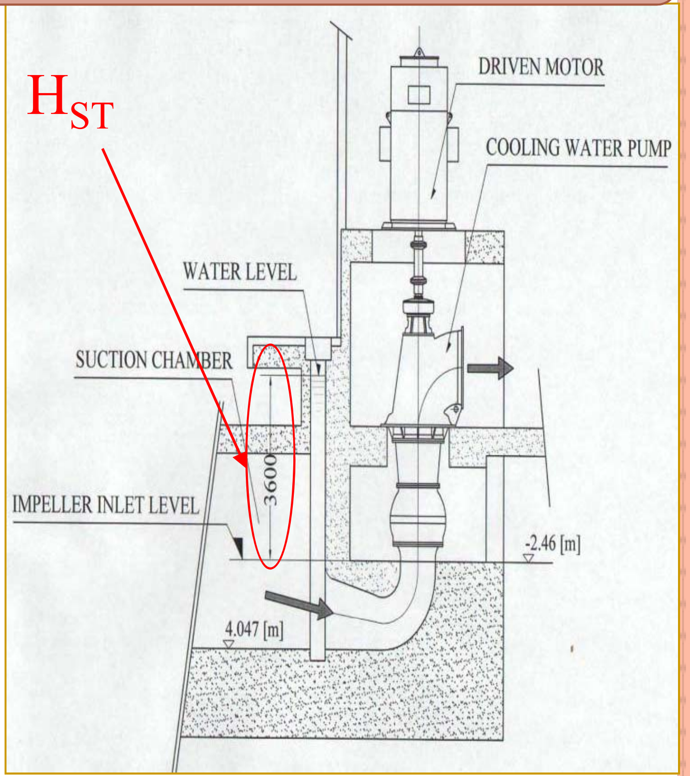
g = 9.81 [m/s2] – the acceleration due to gravity



Hydrostatic and Vapor Pressure Head

…. the vertical distance between the surface of water in the cooling tower basin and the centerline of the pumps

H_{ST} = 3600 [mm] = 3.60 [m] – the hydrostatic head



Temperature ^0C	Vapor pressure bar
0	0.006
5	0.009
10	0.012
15	0.017
20	0.023
25	0.032
30	0.043
35	0.056
40	0.077
45	0.096

…… the absolute pressure at which water will change from liquid to steam at a specific temperature

$$H_{VP} = \frac{p_{VP}}{\rho \cdot g} = 0.574\ [m]$$ -- the water vapor pressure head

$$p_{vp} = 0.056[bar] = 0.056 \cdot 10^5 \left[\frac{N}{m^2}\right]$$ -- the water vapor pressure head

Project Findings

$$\frac{NPSH_A}{NPSH_R} = (1.3 - -2.5)$$ --- According to the pumps manufacturer CCM SULZER and ANSI standard HI 9.6.1:

- For only one pump in operation

$$\frac{NPSH_{A(I)}}{NPSH_{R(I)}} = \frac{11.956}{6.857} = 1.74$$ -- the pump will operate cavitation free

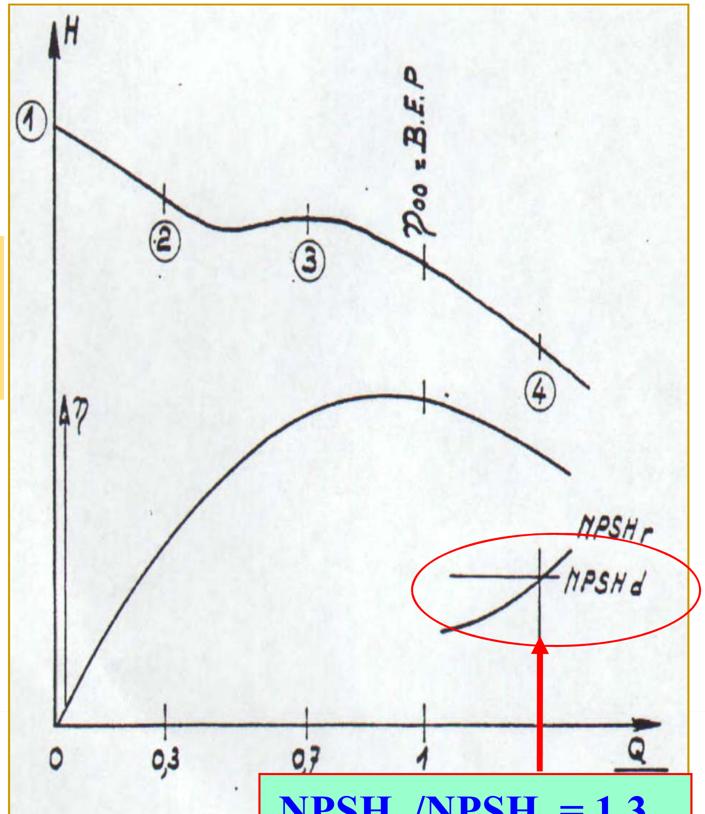
- For two pumps in parallel operation

$$\frac{NPSH_{A(II)}}{NPSH_{R(II)}} = \frac{11.628}{9.19} = 1.265$$ -- the pumps in parallel operation will operate with cavitation

Where

$NPSH_{R(II)} = 2 \cdot NPSH_{R(I)} \cdot \eta_{tot} = 9.19[m]$ -- The required Net Positive Suction Head for two pumps in parallel operation

$\eta_{tot} = 0.67$ -- The total efficiency of the devices in parallel operation



$NPSH_A/NPSH_R = 1.3$

Conclusions and Recommendations

Two pumps in parallel operation will operate with the presence of cavitation.

Hydrostatic head is the only parameter that can be changed

$$NPSH_{A(II)} = H_A + H_{ST}^{'} - H_{L(II)} - H_{VP}$$

If $NPSH_{A(II)} = 1.3 \cdot NPSH_{R(II)}$ Then

$H_{ST}^{'} = 1.3 \cdot NPSH_{R(II)} - H_A + H_{L(II)} + H_{VP} = 4.02[m]$ -- The modified hydrostatic head

$NPSH_{A(II)}^{'} = H_A + H_{ST}^{'} - H_{L(II)} - H_{VP} = 11.947[m]$ -- The modified available Net Positive Suction Head

$$\frac{NPSH_{A(II)}^{'}}{NPSH_{R(II)}} = \frac{11.947}{9.19} = 1.30$$ --- Free cavitation zone

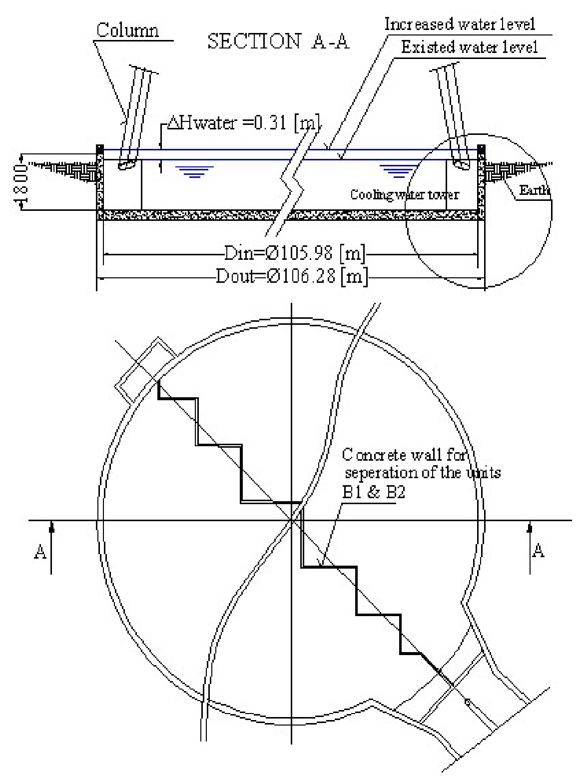
$\Delta H_{ST} = H_{ST}^{'} - H_{ST} = 0.42[m] = 42[cm]$ -- the difference between the modified hydrostatic head to the existed hydrostatic head

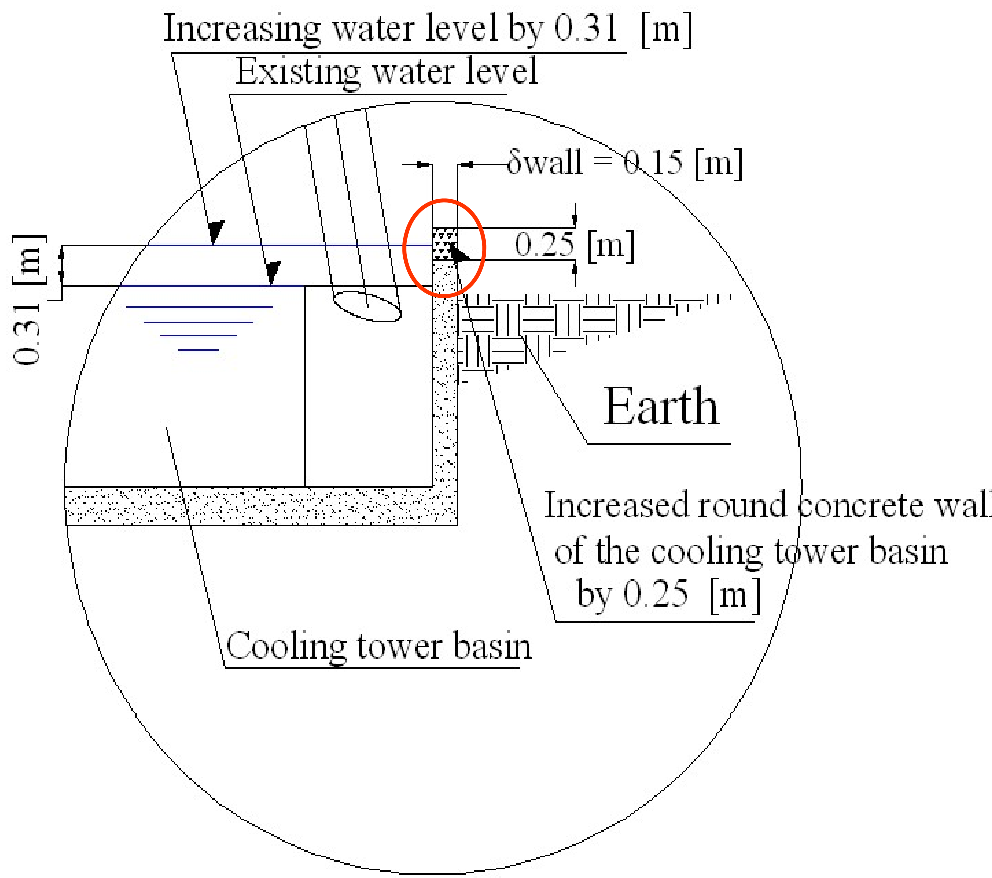
$\Delta H_{ST(REAL)} = \Delta H_{ST} - H_{L-str2(II)} = 31.3[cm]$ -- The water level in the cooling tower basin that should be increased

Where

$H_{L-str2(II)} = 0.107[m]$ -- The head losses through second row of screens

Conclusions and Recommendations





Conclusions and Recommendations

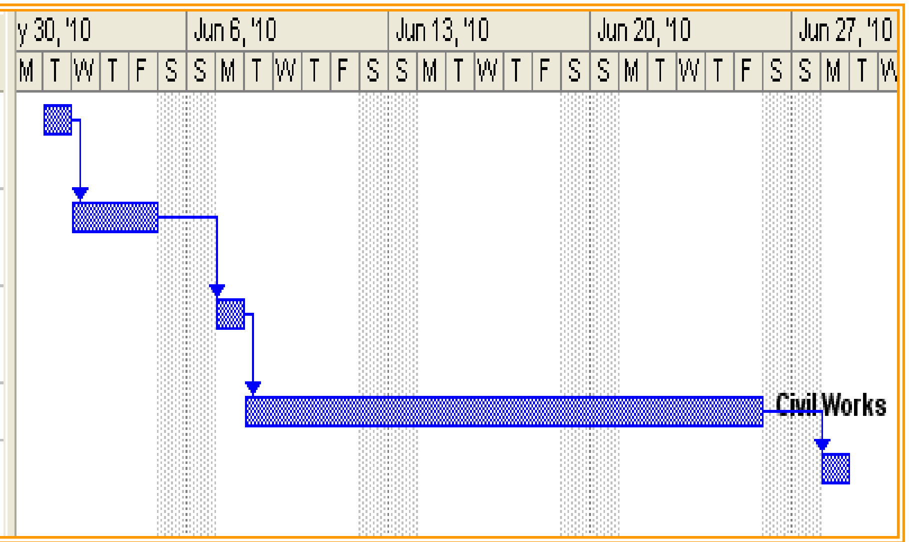
Budget

22 [m3] x 500 [€/m3] = **11000** [€]

Where

- 22 [m 3] -- is the amount for the reinforced concrete …
- 500 [€/m3] – is the total price of the reinforced concrete per cubic meter

	Task Name	Duration	Start	Finish	Predecesso
1	Units B1&B2 out of operation	1 day?	Tue 6/1/10	Tue 6/1/10	
2	Turbine cooling period	3 days?	Wed 6/2/10	Fri 6/4/10	1
3	Emptying the cooling system	1 day?	Mon 6/7/10	Mon 6/7/10	2
4	Civil works	14 days	Tue 6/8/10	Fri 6/25/10	3
5	Filling the cooling system	1 day?	Mon 6/28/10	Mon 6/28/10	4



Plan of work (Gant Chart) for implementing the project

Conclusions and Recommendations

Events

- Each square meter of the cooling tower basin foundation will be loaded for 19 [%] more than it is.
- The efficiency of the cooling tower will drop 2 [%] from the air inlet side.
- The total amount of water that should be added for 31 centimeters in the cooling tower basin is 2620 [m3]

Commissioning phase:

- Calibration of new the water level in the cooling tower basin
- The measurement of the noise level of the pumps with a sound level meter (should be < 90 [dB]

The outcomes will be to:

- Extend the working life of the pumps
- Increase the safe operation of the pumps
- Increase reliance on the cooling system
- Lower level of noise

THANK YOU FOR YOUR ATTENTION